Astrophysics: Model Proposed for Galactic Magnetic Field

A model that accounts for the generation of the galactic magnetic field has been proposed by Eugene Parker of the University of Chicago. At the American Physical Society meeting in Washington, D.C., on 30 April, Parker described a dynamo system in which motions of the interstellar gas generate a small magnetic field that grows until it is strong enough to inhibit the motion of the gas.

Dynamo models involving moving, conducting fluids have been used in attempts to account for the origin of the magnetic fields observed on both the earth and the sun, and the question of generating the galactic magnetic field by random turbulence has been considered. Parker's work, however, is the first attempt to include observed galactic motions in a dynamo model.

The Galaxy

The observational basis for Parker's work goes back to 1949 when W. A. Hiltner (Yerkes and McDonald Observatories) and John Hall (U.S. Naval Observatory) independently detected polarization of light coming from distant stars. The light at the blue end of the spectrum of these stars was strongly absorbed, indicating that there were large amounts of dust between the star and the earth.

On the basis of these observations, Leverett Davis, Jr., and Jesse Greenstein of the California Institute of Technology hypothesized that the alignment of the dust grains in a galactic magnetic field produced the polarization. Specifically, if the grains are elongated and made of a dielectric material, they would became aligned by a process known as paramagnetic relaxation. This hypothesis, which is still generally accepted, has the virtue of accounting for the polarization by a specific mechanism; but it is too general to be involved in the current controversy about the composition of the dust grains.

In addition to observations of polarized starlight, the galactic magnetic field has been studied by measuring the polarization of radio emissions from other galaxies (Faraday rotation) and measuring the splitting of a radio line emitted by hydrogen in our own galaxy (Zeeman effect). Relatively large surveys have been made of polarized starlight and of the Faraday rotation, but knowledge of the galactic magnetic field is still fragmentary. Astronomers generalize that the field is physically associated with the interstellar gas, that it has a field strength of the order of 10^{-5} to 10^{-6} gauss, and that although it tends to follow the spiral arms of the galaxy it is quite irregular. The irregularities seem to be associated with the turbulent motion of the gas, but they are random enough that astrophysicists do not feel they can confidently predict the nature of the magnetic field in those areas where direct measurements have not been made.

In Parker's model it is necessary to specify the observed velocities of the gas in the galaxy. These include both the general, nonuniform rotation (the inner part of the galaxy rotates faster than the outer) and the cyclonic turbulence of the gas clouds. From these, the model generates the large-scale magnetic fields that are observed around the disk of the galaxy but does not account for the irregularities. According to the model, the galaxy is now in a state of relative equilibrium in which the expanding pressures of the gas motion, cosmic rays, and the magnetic field are just balanced by the force of gravity. This equilibrium will not persist because the cyclonic turbulence causes the field to dissipate and regenerate itself every few hundred million years.

Earth and Sun

The first suggestion that a magnetic field could be generated by a rotating, conducting fluid appears to have come in 1919 when the British mathematician Joseph Larmor suggested that the sun's magnetic field—which was first observed in 1908—might be generated by such a process. In 1929 Thomas Cowling of the University of Leeds showed that the model was incorrect. Cowling never developed a solar model of his own, but his work on dynamos laid the foundation for two theories that have been proposed in the last decade.

In 1961 Horace Babcock of Mount Wilson Observatory used Cowling's work as the starting point for qualitative explanations of many of the magnetic properties he had observed on the sun. Last year Robert Leighton of the California Institute of Technology presented a solar dynamo model that rather successfully simulates the behavior of the magnetic field beneath the surface of the sun. The mathematical basis of Leighton's work can be traced back to Cowling, but his model also employs several observational parameters. When programmed on a computer, the model shows how bands with field strengths of a few hundred gauss migrate toward the equator. It also produces the 11-year reversal in field polarity that many believe takes place.

Dynamo models for the generation of the earth's magnetic field were developed independently in the late 1940's by Walter Elsasser (now at the University of Maryland) and Edward Bullard (now at Cambridge University). (Parker's original work on dynamo models and cyclonic turbulence was done in 1955 while he was working with Elsasser.) These models seem to be accepted in their general outlines, but only last month Bullard stated that "there is a conspicuous lack of detail about the possible terrestrial or solar dynamos. This is perhaps due to the use of too highly symmetric models that do not satisfy Bragenskii's criterion. . . ."

This statement refers to the work that the Soviet physicist S. I. Bragenskii has done since 1964 on a general and formal approach to deriving equations for large numbers of geometries capable of generating magnetic fields. Several other mathematicians have been working on this problem recently, and it is now known that there are many combinations of differential rotation and turbulent stirring that could generate magnetic fields.

There are many observations of the magnetic fields of the earth, sun, and galaxy, but there are few points of contact between the models and the observations. Parker's model simulates the gross field of the galaxy and Leighton's model simulates the movement of the magnetic fields beneath the sun's surface. Models of the earth can account for the dipolar field, but no model that includes motions likely to occur in the earth's interior can simulate magnetic drift or field reversals. This research seems to have convinced many that the observed magnetic fields are probably generated by dynamos, but the development of detailed models seems to be many man- and computer-hours in the future.—ROBERT W. HOLCOMB